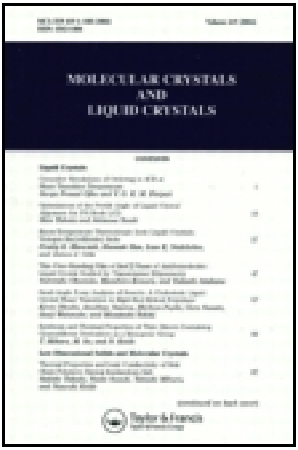

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Orientational Transition in Nematic Liquid Crystal with Hybrid Alignment under Oscillatory Shear

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The optical response of the nematic liquid crystal confined between plates with strong homeotropic and weak planar anchoring (hybrid geometry) under the oscillatory shear has been investigated. Critical shear amplitude above that the director deviates from the planar orientation at the substrate with weak anchoring was found and the dependence of the tilt angle on the displacement amplitude was obtained. The anchoring strength and surface viscosity for the SiO-evaporated substrate was estimated.

Keywords: orientational transition; oscillatory shear; anchoring energy

INTRODUCTION

The orientational behavior of nematics in oscillatory flow has generally been studied in the case of strong surface anchoring at the bounding plates. Recently the optical response of a homeotropically oriented nematic layer with weak surface anchoring under the oscillatory Poiseuille flow was investigated and the surface energy for the glass substrate covered by the chromium-distearyl-chloride was estimated[1]. The problem of the influence of the weak anchoring on the orientational dynamic of nematic layer bounded by the substrates with the bistable anchoring in electric field has also attracted much interest[2-4].

In this paper we present the study of the optical response of a nematic layer in hybrid geometry (weak planar anchoring on one substrate and strong homeotropic alignment on the other) subjected to oscillatory rectilinear shear. We used the oblique SiO-evaporated glass plate with microrelief provided weak anchoring for planar alignment. Varying the oscillatory flow amplitude the possibility of the flow induced orientational transition due to the weak planar anchoring may be analyzed. In order to increase the optical response and the hydrodynamic torque acting on the director the hybrid alignment was chosen.

EXPERIMENTAL

The nematic liquid crystal (MBBA) of thickness d is confined between two parallel horizontal glass plates (see Fig. 1) without spacers. The oblique SiO-evaporated glass plate with microrelief[5] provided weak anchoring for planar

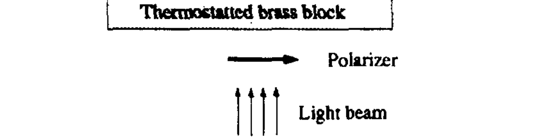

FIGURE 1 Experimental setup.

alignment (upper plate) whereas the strong homeotropic alignment was achieved by using SnO_2-coated float glass plate (bottom). The bottom plate is rigidly fixed to a brass block, which is adjustable in order to control the parallelism of the glass plates (better than *0.5* μm/cm). The temperature of the brass block is kept at 25.5 ± 0.1 °C. The upper plate is attached to a steel rod, which is bound to the membrane of a loudspeaker, driven by a signal generator. The motion of this plate is in the direction of planar orientation (*x*-axis) and is monitored by a semiconductor position-sensitive detector. All measurements were carried out at fixed frequency $f=42$ Hz and the cell thickness was $d=40 \pm 0.2$ μm. Using a sine excitation the displacement of the upper plate is ideally of the form $x(t)=A\ sin(\omega\ t)$ where $\omega=2\pi f$. For the amplitudes up to $A=40$ μm the director oscillates uniformly within flow plane (*x*-*z*) and no pattern forming instabilities are observed. The transmitted light intensity was measured by a semiconductor detector using parallel light (source: diode laser, wavelength $\lambda=670$ nm) between crossed polarizers. The details of this experimental setup are published elsewhere[6].

RESULTS AND DISCUSSION

Signals for a typical upper plate motion and corresponding transmitted light intensity variation in time are shown in Fig. 2 for two shear amplitudes. The transmitted light intensity $I(t)$ between crossed polarizers is imposed by the optical phase difference $\delta(t)$ depending on the director distribution $\theta(z,t)$

$$I(t)=I_0 sin^2(\delta(t)/2), \quad \text{where } \delta(t) = \frac{2\pi}{\lambda}\int_0^d \Delta n_{eff}\left(\theta(z,t)\right)dz \ ,$$

$$\Delta n_{eff}\left(\theta(z,t)\right)=n_o\left[1-\frac{n_e^2-n_o^2}{n_e^2}\cos^2\theta(z,t)\right]^{-1/2}-n_o \qquad (1)$$

and I_0 is incident light intensity, λ is the wavelength of the light, d is the cell thickness, n_o , n_e are the refractive indices. The angle between the plane of director oscillation and the polarization of incident light is 45^0. The director oscillations get larger as the shear amplitude A is increased resulting in a larger change of the phase difference during one period.

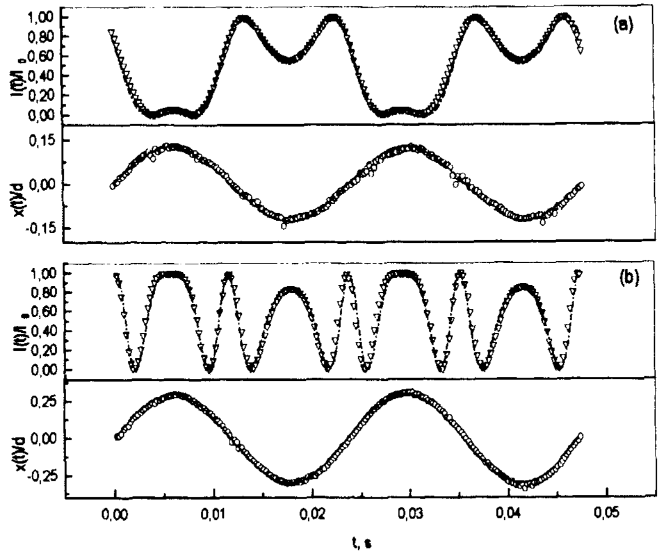

FIGURE 2 The time dependencies of the transmitted light intensity $I(t)/I_0$ (∇) and upper plate displacement $x(t)/d$ (O) for shear amplitudes $A=5.2$ μm (a) and $A=12.1$ μm (b). Curves for $I(t)/I_0$ (- · -) are calculated at $\theta_0=0\,°$ (a) and $\theta_0=4.9\,°$ (b).

The equations governing the director behavior and the flow can be written in our case (Fig. 1) as[7,8]

$$\gamma_1\theta_{,t} - (\alpha_2\sin^2\theta - \alpha_3\cos^2\theta)\,u_{,z} = (K_{11}\cos^2\theta + K_{33}\sin^2\theta)\,\theta_{,zz} + (K_{33}-K_{11})\sin\theta\cos\theta\,\theta^2_{,z} \quad (2)$$

$$\rho u_{,t} = \partial_z\{-(\alpha_2\sin^2\theta - \alpha_3\cos^2\theta)\,\theta_{,t} + [M(\theta)+N(\theta)]\,u_{,z}\} \quad (3)$$

where K_{ii} are the elastic constants, α_i are the viscosity coefficients, $\gamma_1 = \alpha_3 - \alpha_2$, $2M(\theta) = \alpha_4 + (\alpha_5 - \alpha_2)\sin^2\theta$, $2N(\theta) = (\alpha_3 + \alpha_6 + 2\alpha_1 \sin^2\theta)\cos^2\theta$, ρ is the density of liquid crystal. The notation $f_{,i} \equiv \partial f/\partial i$ has been used throughout. The corresponding boundary conditions for angle θ and velocity u are

$$\theta(z=d) = \theta_0, \quad \theta(z=0) = \pi/2\,; \quad u(z=d) = A\omega\cos\omega t, \quad u(z=0) = 0 \qquad (4)$$

The director distribution under oscillatory flow $\theta(z,t)$ was obtained from the numerical solution of the system (2), (3) with boundary conditions (4) for the MBBA material parameters[9,10] ($\alpha_2=-110.4 \cdot 10^{-3}$ N·s/m^2, $\alpha_3=-1.1 \cdot 10^{-3}$ N·s/m^2, $K_{11}=6.66 \cdot 10^{-12}$ N, $K_{33}=8.61 \cdot 10^{-12}$ N, $\rho=10^3$ kg/m^3) and the cell thickness $d=40$ µm. The angle θ_0 on the upper plate was found from the fitting of the experimental dependence $I(t)/I_0$ and the calculated one using Eq.(1). The refractive indices $n_o=1.542$, $n_e=1.7435$ are interpolated from[11] for $\lambda=670$ nm. Our calculations show that even rather small variation of the pre-tilt angle θ_0 by $\pm\, 0.5^0$ leads to a significant changing of the signal shape of optical response $I(t)/I_0$. This allows us to determine the dependence of this angle θ_0 on the flow amplitude with a high accuracy (Fig. 3).

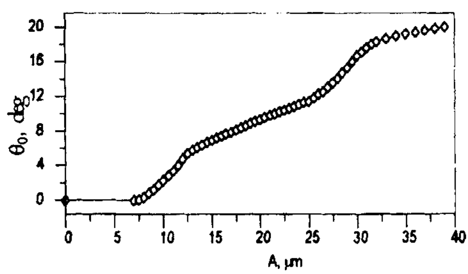

FIGURE 3 The dependence of the tilt angle θ_0 at the substrate with weak planar anchoring on the displacement amplitude A.

It is clearly seen that at the critical amplitude A_c=7.5 μm the director at the upper substrate starts to deviate from the planar orientation and angle θ_0 arises with increasing of amplitude A.

In Fig. 4 the relative intensity of the transmitted light measured at the moment corresponding to the maximum displacement of the upper plate I_{max}/I_0 is plotted as a function of amplitude A. The results of simulation of

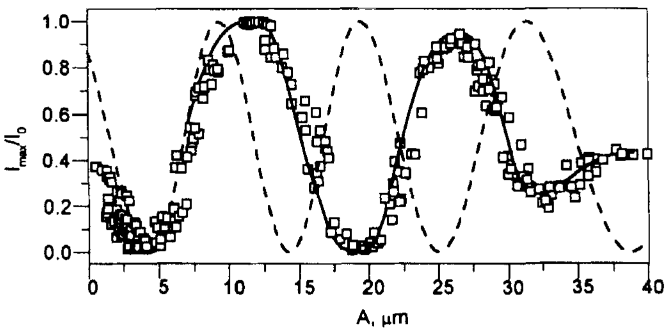

FIGURE 4 The intensity corresponding to the maximum displacement: experimental data (□), calculated for strong planar alignment $\theta_0=0$ (- -) and taking into account $\theta_0(A)$ from Fig. 3 (—).

I_{max}/I_0 for "real" variation of the surface angle $\theta_0(A)$ (see Fig. 3) show a good quantitative agreement with experimental data in contrast to the I_{max}/I_0 calculated under assumption on the strong planar anchoring ($\theta_0=0$).

Let us make a rough estimate of the anchoring strength from the critical flow amplitude. For the dynamical case the following boundary condition should be satisfied[4]

$$\left(K_{11}\cos^2\theta + K_{33}\sin^2\theta\right)\frac{\partial\theta}{\partial z} + \frac{\partial F_s}{\partial\theta} + \eta\frac{\partial\theta}{\partial t} = 0 \qquad \text{on } z=d \quad (5)$$

where F_s is the surface energy per unit area in x-y plane and must possess minimum at $\theta=0$; η is so-called surface viscosity (has the dimensions of viscosity×length). Linearizing the boundary condition (5) around $\theta=0$ one obtain for the perturbation $|\theta_1|<<1$

$$K_{11}\frac{\partial\theta_1}{\partial z}+\frac{\partial^2 F_s}{\partial\theta^2}\theta_1+\eta\frac{\partial\theta_1}{\partial t}=0 \qquad \text{on } z=d \qquad (6)$$

In oscillatory shear flow one have two boundary layers[12,13] of the thickness of order $l\approx[K_{11}/(2\ \gamma_1\ \omega)]^{1/2}$ at $z=0$, $z=d$ and for small relative displacement amplitudes $A_c/d<<1$ one can write

$$\frac{\partial\theta_1}{\partial z}\approx-\frac{A_c}{d}\theta_1\frac{1}{l}\ , \qquad \frac{\partial\theta_1}{\partial t}\approx-\omega\theta_1 \qquad \text{on } z=d \qquad (7)$$

Using the Rapini-Papoular form for the surface energy[14] $F_s=W/2\ \sin^2\theta$ and Eq.(7) one can estimate the anchoring strength

$$W\approx K_{11}\frac{A_c}{d}\frac{1}{l}+\omega\eta \qquad (8)$$

Neglecting the surface viscosity ($\eta=0$) one gets ($A_c=7.5$ μm, $d=40$ μm, $l\approx 0.34$ μm) for the anchoring strength $W_1\approx 3.7\cdot10^{-6}$ N/m. This value is obviously smaller than $W_2=(7.6\pm1.2)\cdot10^{-5}$ N/m which we found from the measurements by means of Freedericksz transition technique in magnetic field for the MBBA layer confined between two SiO-evaporated substrates with weak planar anchoring (identical to the upper plate in present experiments). Note, that using boundary conditions (5) with $\eta=0$ in oscillatory Poiseuille flow experiments[1] also gives smaller value of anchoring strength compare to the independent static measurements. Finally, taking the value W_2 for the anchoring strength, from Eq.(8) one will have for the surface viscosity $\eta\approx2.7\cdot10^{-7}$ N·s/m.

Thus, the surface orientational transition planar → tilt in MBBA hybrid cell with strong homeotropic and weak planar anchoring induced by oscillatory flow has been revealed. From the comparison of the experimental data with the results of direct numerical simulations the critical amplitude for the orientational transition and the dependence of the tilt angle at the substrate with weak planar anchoring on the flow amplitude were found. It was shown that neglecting the surface viscosity in the interpretation of dynamic experiments leads to underestimating the anchoring strength.

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References

[1] L.M. Blinov, S.A. Davidian, V.N. Reshetov, D.B. Subachyus, and S.V. Yablonsky, *Sov. Phys. JETP,* **97,** 1597 (1990).
[2] R. Barberi and G. Durand, *Appl. Phys. Lett.,* **58,** 2907 (1991).
[3] A. Gharbi, F.R. Fekih, and G. Durand, *Liquid Crystals,* **12,** 515 (1992).
[4] P.J. Kedney and F.M. Leslie, *Liquid Crystals,* **24,** 613 (1998).
[5] A.P. Krekhov, M.V. Khazimullin, and Yu. A. Lebedev, *Crystallogr. Rep. (Russia),* **40,** 124 (1995).
[6] T. Börzsönyi, Á. Buka, A.P. Krekhov, and L. Kramer, *Phys. Rev. E,* **58,** 7419 (1998).
[7] F.M. Leslie, *Adv. Liq. Cryst.,* **4,** 1 (1979).
[8] A.P. Krekhov, L. Kramer, A. Buka, and A.N. Chuvirov, *J. Phys. II (Paris),* **3,** 1387 (1993).
[9] W.H. de Jeu, W.A.P. Classen, and A. M. J. Spruijt, *Mol. Cryst. Liq. Cryst.,* **37,** 269 (1976).
[10] H. Kneppe, F. Schneider, and N. K. Sharma, *J. Chem. Phys.,* **77,** 3203 (1982).
[11] M. Brunet-Germain, *C. R. Acad. Sc. Paris,* **271B,** 1075 (1970).
[12] M.G. Clark, F.C. Saunders, I.A. Shanks, and F.M. Leslie, *Mol. Cryst. Liq. Cryst.,* **70,** 195 (1981).
[13] A.P. Krekhov and L. Kramer, *Phys. Rev. E,* **53,** 4925 (1996).
[14] A. Rapini and M. Papoular, *J. Phys. (Paris) Colloq.* **30,** C4–54 (1969).